

# Canopy development and radiation use efficiency of four forage brassica crops

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## Abstract

Forage brassicas are used to supplement pasture fed in times of low growth in summer (e.g. rape and turnips) and winter (e.g. kale and swedes). The physiological mechanisms underlying growth and yield have not been compared between these crops. We analysed the growth and leaf development of four forage brassicas. Turnips, rape, kale and swedes were sown on 18 November 2009, at Lincoln, New Zealand. Leaf counts, solar radiation interception, and biomass were recorded at regular intervals. The turnips and rape were harvested 89 days after sowing; and the kale and swedes 202 days after sowing. The two summer crops had rapid canopy development. The turnips reached canopy closure 300°Cd after emergence ( $T_b=4^{\circ}\text{C}$ ) and the rape at 360°Cd. The two winter crops reached canopy closure much later (~500°Cd). For the turnip, rape and kale crops these differences were principally due to differences in leaf appearance rate but also differences in plant population. Turnips had the shortest phyllochron (47°Cd leaf<sup>-1</sup>) followed by rape (60°Cd leaf<sup>-1</sup>) and kale (76°Cd leaf<sup>-1</sup>). The two summer crops had 50% more plants than the kale. The swede crop had a similar population to the kale but a short phyllochron (51°Cd leaf<sup>-1</sup>) similar to turnips. However, it had a slow rate of canopy closure, indicating that its individual leaves were smaller. Radiation use efficiency was conservative between crops averaging 0.77 g DM MJ<sup>-1</sup> (total solar radiation). The key difference among these forage brassicas was their rate of canopy development principally because of differences in leaf appearance rate.

## Key Words

Kale, Leaf area, Phyllochron, Rape, Swedes, Turnips

## Introduction

Forage brassicas are widely used in New Zealand and Australia to supplement pasture fed at times of low growth or poor quality caused by cool winter temperatures or summer droughts. There is a wide range of brassica types, which are selected according to livestock type (e.g. dairy cattle vs dry stock sheep) and required time of grazing. The four main brassica crops used are: 1. kale (*Brassica oleracea* ssp. *acephala*), a taller crop used primarily for dairy cattle grazing in winter; 2. swedes (*B. napus* ssp. *napobrassica*), a bulb crop used for both sheep and cattle grazing in winter; 3. rape (*B. napus* ssp. *biennis*), a leafy crop used for summer grazing on dryland sheep and beef farms; and 4. turnips (*B. rapa* ssp. *rapa*), used for both summer grazing of dairy cattle and winter grazing on sheep and beef farms.

Yield potential of these forage brassicas differ because of differences in crop growth rate and duration. Summer crops (turnips and rape) tend to have faster growth rates than winter crops (kale and swedes), but because they are harvested much earlier, potential yields are lower. The crop level mechanisms that determine these yield differences have not been examined. Differences in crop growth rate might be associated with differences in either the accumulation of intercepted solar radiation or the efficiency with which this solar radiation is used to produce biomass. The interception of solar radiation is driven by the size of the crop canopy (leaf area index) and how quickly this canopy is established. For a given crop grown in unstressed conditions there is a strong linear relationship between above ground dry matter and accumulated intercepted solar radiation (Monteith 1977). The slope of this relationship is defined as the radiation use efficiency (RUE) (Sinclair and Muchow 1999). Chakwizira et al. (2011) found a RUE for kale of 0.78 g/MJ, but there has been no comparison of RUE across the various forage brassica crops. In this paper we use data from an experiment with four forage brassica crops (kale, swedes, turnips and rape) and analyse key aspects of canopy development, solar radiation interception and radiation use efficiency under optimum (without water or N stress) conditions.

## Methods

### Trial description

Data for this analysis was taken from an experiment described by Fletcher and Chakwizira (2012) (their experiment 2). The relevant details of the experiment that relate to this analysis are described here. The experiment was a split plot design with four brassica crops ('Kestrel' kale, 'Titan' rape, 'Barkant' Turnip and 'Keystone' swede) as the main treatment, with four replicates in randomised complete blocks, and three

fertiliser N treatments as sub-plots. In this analysis, we use only the data from the treatment that received the highest rate of fertiliser N. There was no yield difference between this treatment and the lower rates of N confirming that this rate of fertiliser N was sufficient for maximum crop growth. The experiment was sown at Lincoln, New Zealand ( $43.6^{\circ}\text{S}$ ,  $172.5^{\circ}\text{E}$ ), on 18 November 2009 into a cultivated seed bed using the recommended sowing rate for each crop (Kale and rape—4 kg/ha, Turnips—2 kg/ha, and Swedes—1.5 kg/ha). The trial was fully irrigated to replace ET; and herbicides and pesticides were used prophylactically to manage weeds and insect pests. The turnip and rape crops were grown until 15 February 2010; and the swede and kale crops were grown until 8 June 2010.

#### *Measurements and analysis*

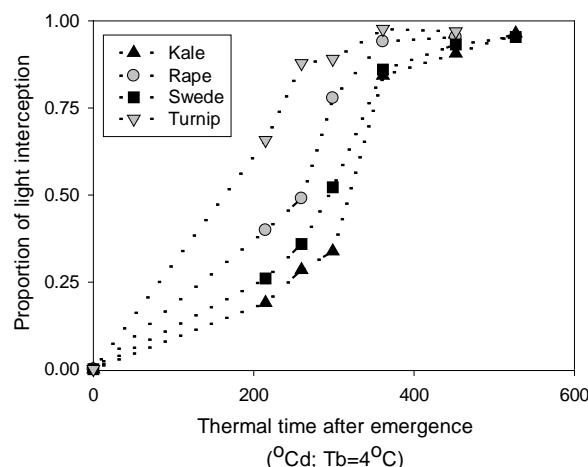
Crop biomass was measured regularly during growth (approximately every 11 days for the turnips and rape; and every 30 days for the kale and swedes). For each of the intermediate harvests a  $0.5\text{ m}^2$  sample was taken and for the final harvest  $3\text{ m}^2$  was sampled. This area was cut to ground level, the number of plants recorded and the sample weighed fresh. A 5-plant sub-sample was dried at  $60^{\circ}\text{C}$  in a fan-forced oven.

Soon after emergence (11 December 2009) five contiguous plants were marked in each plot. Observations of fully emerged leaves were made every 3–7 days until final harvest. In order to calculate a phyllochron ( $^{\circ}\text{Cd}$  between the emergence of successive leaves) a linear regression, with groups, was undertaken for leaf number against accumulated thermal time after emergence, calculated using a base temperature of  $4^{\circ}\text{C}$  (Adams et al. 2005). This analysis tested whether there was evidence for a distinct phyllochron for each crop or a single value for all crops. The regression relationships were forced through the origin and the phyllochron ( $^{\circ}\text{Cd}/\text{leaf}$ ) was calculated as the reciprocal of the slope.

Intercepted solar radiation was measured using a ceptometer (Decagon Devices, Pullman, WA, USA). Measurements were taken around solar noon on clear cloudless days, at 4–7 day intervals, from 15 December 2009 until canopy closure (greater than 95% light interception). At each sampling, one above canopy measurement and five below canopy measurements were taken. Solar radiation interception was calculated as the product of the proportion of solar radiation intercepted, calculated using the ceptometer data, and incident solar radiation measured approximately 100 m from the experimental site. Linear interpolation (based on days) was used to predict solar radiation interception between measurements. This intercepted solar radiation was accumulated through time. The RUE was taken as the slope of a linear regression, forced through the origin, of crop biomass against accumulated intercepted solar radiation. Again a linear regression with groups was used to test whether there was evidence for distinct RUEs for each crop or that a single value for all crops was sufficient. Biomass measurements taken after crop maturity were eliminated from this analysis. Furthermore, only the first two biomass measurements from the swede crop were included, due to an undiagnosed disease problem later in the season. All statistical analyses used Genstat 14.2.

## **Results and discussion**

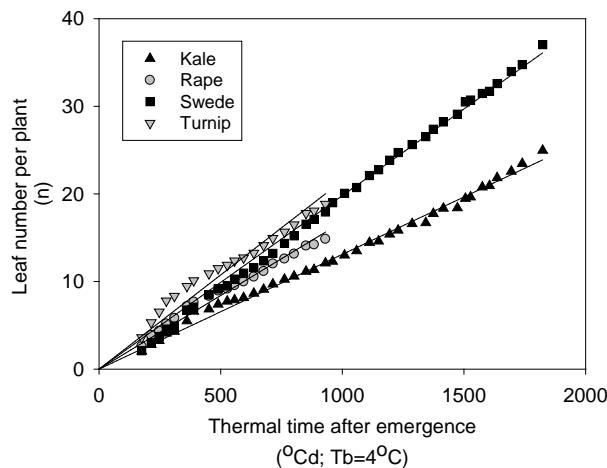
### *Canopy development*



**Figure 1. Proportion of light intercepted by four forage brassica crops against thermal time after emergence. Grey symbols are summer-grazed crops and black symbols winter-grazed crops.**

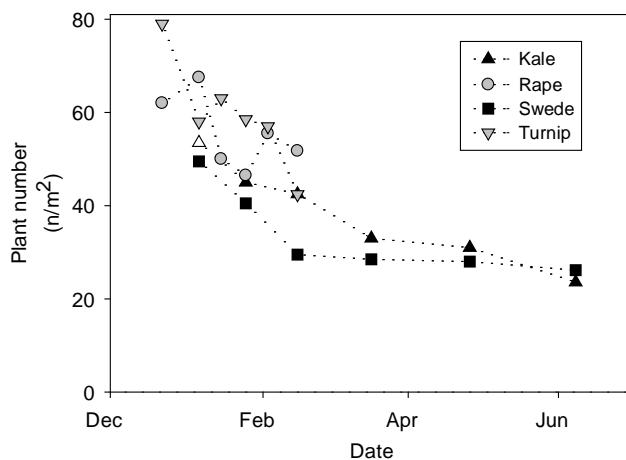
There were clear differences in the rate of canopy closure between the crops. The two summer crops reached full canopy (<95% light interception) quickly compared with the two winter crops. Turnips reached canopy closure at approximately 300°Cd after emergence and rape 360°Cd after emergence. Kale and swedes both reached canopy closure at about 450°Cd after emergence (Figure 1).

The differences in leaf appearance rate ( $p<0.001$ ;  $R^2 = 0.99$ ) reflected these differences in canopy closure (Figure 2). Kale had the slowest rate of leaf appearance with a phyllochron of 76°Cd/leaf. Rape had a phyllochron of 60°Cd/ leaf and the swede crop a phyllochron of 51°Cd/leaf. Turnips had the most rapid leaf appearance rate with a phyllochron of just 47°Cd/leaf. For both the rape and the turnips there was evidence ( $p<0.001$ ) to suggest that the phyllochron was greater early in the growth cycle. For turnips the phyllochron was 24°Cd before an accumulated thermal time of 280°Cd, and 61°Cd afterwards. For rape the phyllochron was 43°Cd before an accumulated thermal time of 355°Cd, and 73°Cd afterwards. Interestingly, the break in these two relationships coincided with the approximate time of canopy closure for each crop (Figure 1).



**Figure 2.** Plant leaf number against thermal time after emergence (Linear regressions are  $y=0.0131x$  for kale,  $y=0.0168x$  for rape,  $y=0.0198x$  for swedes and  $y=0.0215x$  for turnips;  $R^2=0.99$ ). Grey symbols are summer-grazed crops and black symbols winter-grazed crops.

There was an approximate exponential decline in plant number, caused by inter plant competition, for all species throughout the experiment for all crops (Figure 3). In general, the turnip and rape crops had approximately twice the number of plants/m<sup>2</sup> than kale and swedes. At final harvest the kale and swede crops had approximately 25 plants/m<sup>2</sup> which was significantly less ( $p<0.001$ ) than the 47 plants/m<sup>2</sup> for the turnips and rape.



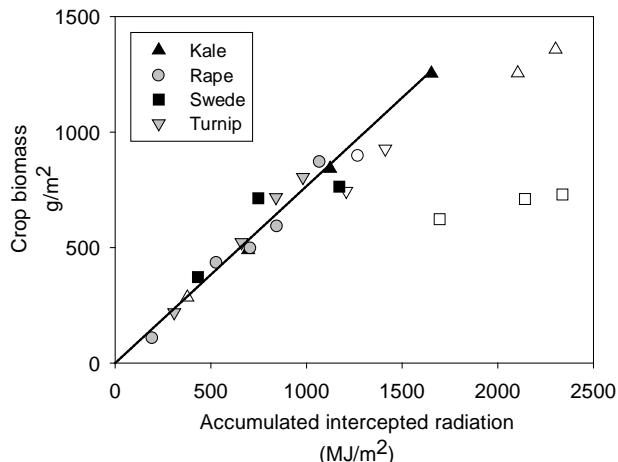
**Figure 3.** Plant numbers against calendar day. Grey symbols are summer-grazed crops and black symbols winter-grazed crops.

The faster canopy closure by turnips compared with rape, was due principally to a shorter phyllochron for turnips, given that plants/m<sup>2</sup> were similar for these two crops (Figure 3). The comparatively slower rate of canopy closure by kale was due mainly to a longer phyllochron, but also partly due to less plants/m<sup>2</sup>. The

only crop that did not fit this pattern was swedes. This crop had a slow rate of canopy closure, similar to kale, but a short phyllochron, similar to turnips. This implies that the individual leaves of swedes were much smaller in area than kale.

#### Radiation use efficiency

There were no significant differences in RUE between the crops ( $R^2=0.95$ ), with the mean RUE being 0.77g /MJ (Figure 4). This value is similar to unstressed kale, turnips and rape crops (Chakwizira et al. 2011, Chakwizira and Fletcher 2012). Our results have demonstrated that these forage brassica crops have similar RUEs when tested in unstressed conditions. However, these values may change under water (Chakwizira and Fletcher 2012) or N stress.



**Figure 4. Crop biomass vs accumulated intercepted radiation. Grey symbols are summer-grazed crops and black symbols winter-grazed crops. Open symbols were deemed to be after peak crop growth and were not included in the regression. The regression line is ( $y = 0.77x$ ;  $R^2 = 0.95$ ).**

#### Conclusion

Our results show that radiation use efficiency did not differ between these forage brassica crops. The differences in biomass between these crops were mainly associated with the rate of canopy closure and crop duration (amount of incident solar radiation). The rate of canopy closure was determined by the rate of leaf appearance. Turnips had the fastest leaf appearance rate and were quickest to close their canopy. In contrast, kale took the longest time to close its canopy and had the longest phyllochron. These brassica crops could be incorporated into an existing simulation model (Wilson et al. 2004) by adjusting the rate of leaf appearance and canopy development for each crop.

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